Information Theory for Molecular Communication in Nanonetworks

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Towards an Information Theory for Molecular Communication

- **Physical Channel Model**
  - How information is transmitted, propagated and received when a molecular carrier is used

- **Noise Representation**
  - How can be physically and mathematically expressed the noise affecting information transmitted through molecular communication

- **Information Encoding/Decoding**
  - How can information be encoded for a proper transmission using molecular communication

**Molecular Channel Capacity**
Molecule Diffusion Communication: Exchange of information encoded in the concentration variations of molecules.
Objective of the Physical Channel Model


Derivation of DELAY and ATTENUATION

as functions of the frequency and the transmission range

- Non-linear attenuation with respect to the frequency
- Distortion due to delay dispersion
Modeling Challenges for the Physical Channel


- **Transmitter**
  - How chemical reactions allow the modulation of molecule concentrations as transmission signals?

- **Propagation**
  - How the “particle diffusion” controls the propagation of modulated concentrations

- **Receiver**
  - How chemical reactions allow to sense the modulated molecule concentrations from the environment and translate them into received signals
Molecule Diffusion Channel Model


Transmitter Model

- Design of a chemical actuator scheme (chemical transmitting antenna)

- Analytical modeling of the chemical reactions involved in an actuator

- Signal to be transmitted $\rightarrow$ Modulated concentration
Molecule Diffusion Channel Model


Propagation Model

- Solution of the diffusion physical laws (FICK's First and Second Laws (1855), Relativistic Diffusion Process) in the presence of an external concentration modulation

- Modulated concentration → Space-time concentration evolution
Molecule Diffusion Channel Model

Receiver Model

- Design of a chemical receptor scheme (chemical receiving antenna)

- Analytical modeling of the chemical reactions involved in a receptor

- Propagated modulated concentration $\rightarrow$ Received signal
Conclusions


- A mathematical model for the physical molecular diffusion channel

- Non-linear channel attenuation both in frequency and Tx-Rx range

- Channel Tx-Rx delay varies in frequency → dispersion phenomena when the signal propagates
Current Research

- Noise → incorporated into the channel model

- Study of possible noise sources:
  - When information modulates the molecule concentration
  - When information is encoded into molecule chemical features (e.g., type, structure, polarization, etc.)
Noise Representation
Molecule concentration modulation

- Diffusion Process
- Chemical change
- Brownian motion
- Turbulence
- Information mixing

Nano mac 1
Nano mac 2
Nano mac 3

same molecule as
Noise Representation
Molecule chemical feature encoding

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<th>Symbol</th>
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Extinction latency
Cross-symbol interference
Symbol usage desynchronizing
Information Encoding/Decoding

- **Concentration Modulation** (e.g. Ca^{2+} ion signaling)

- **Information Encoding Based on Chemical Features** (e.g. pheromone communication)

- **Encapsulation of Information Carriers** (e.g. DNA vesicle encapsulation, pollen/spores communication)
Future Research and Challenges

- Properly model all the noise sources
- Information encoding/decoding and modulation pattern
- Channel Capacity computation
- Channel multiple access problem
- Addressing issue (routing problem)
- Higher layers development
Thanks for your attention

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